ARTISANAL AND SMALL SCALE GOLD MINING AND MERCURY CONTAMINATION – Draft Nov. 2014

Introduction

Artisanal and small-scale gold mining (ASGM) provides a basic livelihood for an estimated 15 million miners and their families worldwide and for a large number of small enterprises which support the mining activities[1]. The high price of gold has attracted an increasing number of workers, most of whom have turned to mining to escape extreme poverty, unemployment or landlessness.[2] However, current ASGM practices use large amounts of mercury, such that ASGM now constitutes the most significant source of anthropogenic mercury emissions in the world.[3] This mercury, in a variety of forms, poisons the miners and their communities and also impacts ecosystems and human health worldwide.

More then one third of all anthropogenic mercury emissions to the air come from ASGM activities[4]. In turn, about 80% of mercury reaching the oceans is a result of deposition from the atmosphere. The remaining 20% comes via river systems, including both natural and anthropogenic sources (such as mining). At the same time, mercury released into the aquatic environment from ASGM activities can be locally significant in terms of loads and ecological impacts.

This is a wide and varied "sector". Gold occurs in a range of different geological and mineral settings and the methods for extracting and concentrating the gold reflect the local social and institutional contexts. Consequently, practical approaches to developing sustainable local forms of ASGM will vary in important ways according to the specific circumstances.

In 2002, the Global Mercury Project was established by GEF, UNDP and UNIDO to reduce the amount of mercury used in ASGM and released to the environment. Subsequently, UNEP created a Mercury Partnership for Artisanal and Small Scale Gold Mining, aimed at implementing low-mercury and mercury-free ASGM techniques. In addition, both the US and the EU have placed restrictions on the export of mercury in efforts to reduce its availability in world markets and to increase the price.

The recent Minamata Convention on Mercury will introduce a ban on new mercury mining, controls of air emissions of mercury and regulation of mercury use in ASGM,

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[1] Veiga, M. M., Maxson, P. A., and Hylander, L. D. (2006). Origin and consumption of mercury in small-scale gold mining. *Journal of Cleaner Production, 14*(3–4), 436–447. doi:10.1016/j.jclepro.2004.08.010
[2] UNEP. (2011) Reducing Mercury Use in Artisanal and Small Scale Gold Mining Report. http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/ASGM/Techdoc/UNEP%20Tech%20Doc%20APRIL%202012_120619%20with%20links_web.pdf
[3] UNEP (2013) Mercury: Time To Act http://www.unep.org/publications/contents/pub_details_search.asp?ID=6281
[4] AMAP/UNEP, 2013. Technical Background Report for the Global Mercury Assessment 2013. Arctic Monitoring and Assessment Programme, Oslo, Norway/UNEP Chemicals Branch, Geneva, Switzerland.

as part of wider efforts to reduce mercury in the environment. The Convention builds on many years of efforts by local and international agencies and organisations, who continue working to initially reduce and ultimately eliminate mercury from ASGM activities.

ASGM and use of mercury

Some gold deposits can be worked by simple hand technologies, such as panning, but many involve digging out an ore, crushing and concentrating it, and then extracting the gold from the concentrate. Relatively simple technologies can be used to carry out these processes, although the details vary widely and the systems have typically evolved to suit the specific local circumstances.

The value of mercury to artisanal miners lies in its ability to form an amalgam with gold, which allows the miners to capture the fine gold particles in the concentrate into a larger and more manageable "ball" of mercury amalgam. The ball of amalgam is then heated to evaporate and drive off the mercury, leaving behind a pellet of relatively pure gold. However, amalgam burning often takes place at or close to miners' dwelling areas and consequently their families and communities may inhale significant amounts of mercury vapour, which eventually can be absorbed by the kidneys and brain.[5]

Mercury exposures can cause miscarriages, respiratory failure, psychotic reactions, cardiovascular disease and death, with pregnant women and children especially at risk. The vaporized mercury enters the local environment or is transported in the atmosphere, subsequently precipitating into other ecosystems.[6] In anaerobic sediments of rivers and ponds, bacteria convert this mercury into highly neurotoxic methylmercury (MeHg), which bioaccumulates up the aquatic food chain, affecting rivers, fish and crops (including rice), and negatively impacting biodiversity.[7]

ASGM mining methods are typically not efficient and considerable amounts of gold (and mercury) are often left in the "tailings", the fine waste material from the concentration stage. This presents both an opportunity and a problem: further gold can be extracted but often this is done using cyanide, which is another toxic (but shorter lived) component of the mining process. In addition, the fine mercury "flour" in the tailings may be released directly into local water systems causing severe pollution.

[5] ATSDR (1999) Toxicological profile for mercury. 615 pp.

[6] Appleton JD, Williams, TM, et al (1999) Mercury contamination associated with artisanal gold mining on the island of Mindanao, the Philippines. Science of the Total Envt 228: 95-109; Limbon D, Kumampung J, et al (2003) Emissions and environmental implications of mercury from artisanal gold mining in north Sulawesi, Indonesia. The Science of the Total Envt 302: 227-236.

[7] Same as above; Peru Support Group. (2012) Artisanal and Small-Scale Gold Mining in Peru: A Blessing or a Curse? http://www.perusupportgroup.org.uk/files/fckUserFiles/file/Artisanal%20and%20Small-scale%20Gold%20Mining%20in%20Peru.pdf; Rohtenberg, S. E., Xinbing, F., et al. (2012) Environment and genotype controls on mercury accumulation in rice (Oryza sativa L.) cultivated along a contamination gradient in Guizhou, China. Science of the Total Envt. 426: 272-80.

Reducing mercury use

Mercury amalgamation was developed in support of silver and gold extraction in the New World in the sixteenth century and has been used in different forms ever since. Efforts have been underway for decades to deal with the impacts of mercury from ASGM. For some governments, the approach has been to ban mercury or to ban ASGM completely, partially at least because of its competition with the formal (and tax-paying) mining sector.

However there is an increasing recognition that a reformed and modern ASGM sector can be a valuable part of a country's mining industry and that new approaches are required for the formalization and regulation of ASGM[8]. Some governments are moving in this direction but there is a need for more governments at local and national levels to approve and codify existing good institutional structures and to provide technical support for improved processing. This would likely include cheap high efficiency and chemical free gravimetric concentrator systems, combined with more centralised tailings collection and processing systems which can take advantage of scale.

Increases in gold prices over recent years have resulted in significant expansion of ASGM activities in many countries and sustainable solutions to reduce mercury emissions and legacy contamination are urgently needed, together with the local capacity to implement them. Approaches being applied range from simple mercury-recapture technology such as retorts and fume hoods to higher-tech solutions such as shaker tables and centrifuges which require significant investment and are relevant to larger groups of miners. Practical technologies for reducing and eventually eliminating mercury use are well understood, in general terms[9]. The challenges lie in identifying and adapting the most appropriate mix of techniques for a given mining area and set of miners and in persuading the miners to adopt them.

Miners and others in local industries are often broadly aware of potential impacts and of pollution issues but avoidance of mercury is not a high enough concern to cause the majority of the miners to change long established methods. Most miners operate on a short term basis, needing to earn cash income every day, and they have very little slack for experimentation or non-productive operations.

The critical factor in persuading the mining communities to adopt new technology is cost-effectiveness. The new approach must result in increased gold recovery

[8] Telmer K. and Persaud A. (2013) Historical and Modern Government Responses to Artisanal and Small Scale Gold Mining. *Rocky Mountain Mineral Law Foundation (RMMLF) and the International Bar Association, Special Institute on International Mining and Oil & Gas Law, Development, and Investment*, Cartagena, Colombia, April 22-24, 2013.

[9] Telmer, Kevin and Daniel Stapper (2012). Reducing Mercury Use In Artisanal And Small-Scale Gold Mining - A Practical Guide. UNEP, Geneva, Switzerland

and/or reduced effort. Gold ores vary considerably and therefore different processing and extraction procedures need to be used. Miners are also typically quite risk averse and will only adopt change when the benefits have been clearly demonstrated to them. In the larger and more organised mining systems, there is likely to be more investment and there may be more opportunity to promote and demonstrate improved approaches.

ASGM operations are often "informal" in the sense that they do not conform to government regulations and do not pay required taxes and royalties on gold that is mined. However, informal does not mean unorganised. There are many different institutional structures in informal mining operations across the world, including cooperatives, contract labor systems, revenue sharing and so on. Encouraging mining groups to organize into larger groups and formalize would be an important step towards improving working conditions and environmental consequences but many governments are reluctant to move in this direction.

The organisational structure of the activities is crucial to implementation. An ASGM operation involves mining, preparation and concentration, gold recovery, and gold processing. Each step requires skills and equipment as well as expertise, which are more likely to be available in a more established and larger scale operation. Selecting the right "upgrade" to promote at a particular site depends on the type of ore, the scale and sophistication of the operations, the knowledge and organisation of the mining community, and their access to technical and financial resources.

Making progress

The recently signed Minamata convention on mercury is a significant step in bringing attention and resources to the problems. ASGM is only one aspect of the convention, which also addresses broader production and use of mercury. Much effort going into promoting increased adoption in the field of reduced mercury or no mercury processing. Initially this requires considerable external technical support and education/training for mining communities but the hopes are to diffuse and scale up through replication of local successes in the broader mining community of an area and more widespread adoption of demonstrated improvements. Allied to these activities are parallel efforts in working with governments and the formal mining sector to upgrade the conditions and productivity of the informal sector.

The most severe form of mercury misuse in ASGM is whole ore amalgamation. In this approach, large quantities of mercury are added to the ore at the initial stages of crushing. This results in very inefficient amalgamation and large wastage, with most of the mercury being discharged with the tailings. Education and demonstration can often convince miners to move away from this approach.

More commonly, mercury is added at the last stages of concentration or for final recovery. At this point, it can be very effective in consolidating fine gold particles into the amalgam, which is easy to separate out and then to burn in order to release the gold. Many efforts to reduce mercury use in ASGM have focused on reducing the amount of mercury used and on recovering the mercury that is normally burned off (and lost as a toxic vapour). The most widely used technique is the retort. This refers to any method for trapping and condensing the vapour from the mercury burning, so that it can be reused. Many different types of retorts have been tested and successfully implemented across the world through the efforts of a large number of organisations, often supported by international donors.

Significant progress has been made in introducing retorts (and related approaches) but the scale of the problem remains very large and while mercury reduction through retorts reduces the quantities of mercury released it does not eliminate the mercury problem.

Enhanced gravimetric separation
In persuading miners to move away from mercury methods, one of the technical approaches that has great potential for at least some ore types, is enhanced gravimetric separation. This technology is based on upgrading the milling and grinding of the ores and also introducing more effective sluicing and screening of the concentrate, so as to result in a final concentrate with a higher percentage of gold. This concentrate is then heated with a flame to extract the gold ("smelting"). Borax is added (as a "flux") to the concentrate to lower the melting point and to enhance gold recovery. Therefore this approach is sometimes known as the "Borax Method". Borax is an environmentally benign chemical commonly used in products such as detergents, fire retardants, and ceramic glazes.[10] Borax has been used in ceramics, mining and metallurgy for more than 200 years.

The borax method was developed as a practical approach by gold miners in the area of Luzon in the Philippines nearly 30 years ago. This enhanced gravimetric method is most effective where the gold particles in the ore are relatively large and therefore can be separated easily without the use of mercury amalgam. In miners terminology, it works best for a "visible" (or semi-visible) deposit where the specks of gold can be identified with the eye. Detailed geo-chemical analysis of the ores will, of course, help to determine the effectiveness of the approach.

The key issue in these methods is to find the right gravimetric parameters to produce a good concentrate. Based on the characteristics of the local ores, it will often be necessary to explore variations of the "direct smelting method". These variations could include different milling or grinding techniques and alternate gravimetric concentration methods such sluicing or screening using different sluice

[10] Material safety data sheet: sodium borate (borax, fused) MSDS [Internet]. Houston, Texas: Science Lab. 2005 [cited 2012 May 16]. Available from: http://www.sciencelab.com/msds.php?msdsId=9924967; Summary of Health Risks Associated with Using Borax in ASGM. Blacksmith Institute. http://blacksmithinstitute.org/files/FileUpload/files/Borax%20in%20ASGM%20Final%20-%20April%201%202013.pdf

box materials, changing the flow of ground ore through the sluice box, and so on. As projects and trials are carried out in a growing range of conditions, knowledge is being gained on the most effective mix of techniques.

Increased gold recovery from tailings

The mercury that forms the amalgam is only part of the overall problem. Most ASGM operations are inefficient and the tailings from the concentration processes (the fine waste rock material) contain both lost gold and significant amounts of mercury that have gone through the system. Miners understand that they are not able to extract all of the gold in the ore that they process and it is common practice to reprocess tailings using cyanidation or to sell the tailings to a third party who may have a cyanidation plant. The tailings, from processing or from cyanidation, accumulate locally or are lost into the local environment throughout the lifetime of the operations and can affect nearby populations for generations unless cleaned up. Unsecured tailings dams are especially dangerous, as they are susceptible to natural disasters and often drain directly into streams used for drinking water, fishing or irrigation.

Tons of mercury are lost each year due to inefficient processing techniques, such as excessive grinding of ore or adding more mercury than necessary, as well as loss of mercury flour[11]. Even if the tailings are put through cyanidation, the process does not recover all the amalgamated gold associated with the flour, resulting in significant amounts of gold and mercury left in both mining and cyanidation plant tailings. Worldwide, this unrecovered gold could potentially translate to a tremendous value; perhaps millions of dollars. Recovering the gold could potentially offset the cost of remediation, and even result in profits that could be reinvested in communities or used for other remediation projects. Efforts are ongoing to test and refine techniques which might allow profitable recovery of this gold from tailings

Blacksmith's activities

Blacksmith has been working with a number of communities and local groups where support was requested to deal with ASGM and mercury issues. Interventions have been supported in West Africa, Southeast Asia and Latin America. Efforts continue along with other international agencies and groups to identify mercury-free technologies and production processes which are suited to the different local contexts.

Initial steps can be taken to reduce mercury use and to minimise mercury release to the environment, while remaining focused on the objective of converting to mining methods which are mercury free and which reduce or eliminate the use of cyanide

[11] Appel, P. W. U., Na-Oy, L., et al. (2011) Cleaning mercury polluted mine tailings in the Philippines, Danmarks og Grønlands Geologiske Undersøgelse Rapport 2011/127, 39pp.

or other toxic chemicals. Finding effective ways to reprocess tailings to recover gold and then to stabilise the tailings would be a major breakthrough.

Current work includes supporting the development of technology that can recapture mercury and mercury flour from contaminated soil and tailings, and thus potentially offset remediation costs as well as provide additional source of revenue for community development.

The challenge that the development community faces is to reach out to so many ASGM groups worldwide. Effective and convincing demonstration projects combined with support for dissemination to surrounding mining communities are needed, in order to upgrade mining activities at the largest possible number of sites. A South-South technology transfer model is being tried to convert miners to mercury-free practices, using mining expertise from the Philippines. An incentive-based approach, incorporating learning-by-doing can help to ensure lasting and self-replicating results.

As countries seek to reduce mercury contamination from ASGM in order to comply with the Minamata Convention, there will be an increased demand for scalable, successful mercury-free mining and remediation models. For miners, enhanced income is the basic motivator to adopt environmentally safe practices. For governments, which ultimately bear responsibility for remediation and its costs, finding and disseminating cost-effective and self-replicating mercury-free practices and remediation technology would be ideal.

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